THE ECONOMICS OF OIL AND GAS SUPPLY

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I. Introduction: the economic concept of "supply"

The determinants of oil and gas supply are extremely complex, as mere recitation of some distinctive characteristics of the industry--and some equally distinctive governmental practices with respect to it--readily suggests. The complete production cycle, from initial exploration to exhaustion of deposits, is very long--often fifty years or more. Exploration and development, especially the former, are characterized by great uncertainty as to results. Absent regulation, expected future prices and costs are a major influence on current rates of extraction from developed reservoirs. Ownership of extracted oil and gas in the United States is governed basically by the "rule of capture," which, with multiple interests in a common reservoir, encourages rapid exploitation;[1] yet ultimate recovery from an oil reservoir is inversely related to the rapidity of exploitation. Largely for this reason, oil well densities and rates of extraction are regulated under conservation statutes in most producing states. Oil and gas are joint products and, to a limited degree, mutually competitive products. Apparently to provide relative encouragement to oil and gas production, income from these minerals is accorded differentially low federal tax rates by means of special depletion and other allowances. Oil imports into the United States are limited by a quota system. The wellhead price of natural gas destined for interstate transmission is subject to federal regulation, but there is no direct regulation of crude oil prices at any governmental level.

Within the limits of this short paper it is impossible to deal with the international aspects of oil and gas supply. It is necessary to confine the discussion to the domestic scene, and even then to proceed at a relatively high level of abstraction. It is all the more essential, therefore, that the concept of supply employed be quite clear from the outset.

"Supply" is a functional economic concept developed explicitly for use in the analysis of relative prices and the associated allocation of productive resources among competing uses. Functionally conceived, supply is not a given stock or rate of output of a good, but rather is a schedule of alternative quantities of a good that would be offered for sale during a specified time at various alternative prices. For reasons to be made clear below, the quantities in the supply schedule are nearly always positively related to price. The companion concept is "demand": a schedule of alternative quantities of a good that would be purchased during a specified time at various alternative prices (the quantities being negatively related to price). Supply and demand so conceived indicate for each good and time period a unique market-clearing price, hence the volume of sales that tends to be effected. Given demand, an increase in supply, i. e., an increase in the quantity offered at each price, decreases the market-clearing price and increases the volume of sales. A decrease in supply has the opposite effect, of course.

It should be readily apparent that the quantity of a good offered for sale at a given price depends in some sense upon the costs of making units of the good available for sale. In markets where there are many actual and potential sellers, so that no one can significantly affect the price through his separate offers, it is in the interest of any seller to offer a unit whenever the necessary increment to his total costs is less than the price.[2] It follows that the quantity offered by all sellers taken together is pushed to the point where the incremental cost of the last unit--the marginal cost--for each seller is equal to the price. Thus, supply is a function of marginal costs at alternative levels of output. With a given state of technology and over the usually relevant range of output, marginal costs tend to rise with increasing quantities offered for sale. This results from diminishing marginal productivity of variable inputs and the progressive addition of higher-cost facilities to make increasing quantities available. Consequently, with a given state of technology, it is only at increasing prices that increasing quantities are offered for sale. This is the reason why in the short run an increase in demand normally increases the market-clearing price.

The elasticity of supply is a measure of the degree to which quantities offered for sale respond to a change in price. If the response is small (supply inelastic), then a given change in demand causes a relatively large change in the market-clearing price and a relatively small change in the volume of sales effected. If the response is large (supply elastic), then the relative effects on price and sales volume are reversed.

As suggested by a qualifying phrase used above, the state of technology is a fundamental determinant of supply in any industry. A technological change which reduces marginal costs at all levels of output increases the quantity offered for sale at any given price; that is to say, it increases supply as defined. Given demand, such technological change decreases the market-clearing price and increases the volume of sales effected. Technological progress thus limits the increases in price necessary to induce increasing quantities of output over time; if rapid enough, it can permit increasing quantities of output over time at decreasing prices.

Quite aside from technological change, the characteristics of supply in any industry depend upon the time period specified as relevant to a given market problem. Since supply is a function of marginal costs, defined as the increments to total costs necessary to add successive units to the quantity available for sale, supply depends upon the types of costs that are variable during the specified period. In relatively short periods, during which productive facilities and related expenses may be regarded as fixed, only user costs[3] and such direct costs as labor and materials are variable. Within the technical capacity of the installed facilities, therefore, only such user and direct costs limit the different quantities of product made available for sale at different prices. Supply tends to be relatively inelastic; and if demand is sufficiently depressed, sales may willingly be made at prices below full costs per unit. In the long run, however, all costs are variable--including the costs of replacing and adding to facilities. Consequently, it is total costs that limit the quantities made available for sale at different prices in the long run. Long-run supply tends to be substantially more elastic than short-run supply, and the long-run market-clearing price always covers full costs per unit.

Following a brief general description of the oil and gas production cycle, we shall consider the characteristics of supply--and their implications--in the decision periods corresponding to different phases of that cycle.

II. The oil and gas production cycle

Oil and gas are found in underground formations of porous rock surrounded by impervious materials that trap the migratory minerals and confine them under pressure. Relative to the total volume of earth down to the depths now accessible to drillers, oil and gas bearing formations are neither large nor densely distributed, even in those major sedimentary basins where they are most concentrated. Bearing formations vary widely in size, depth, porosity, pressure and other economically relevant characteristics. The specific qualities of the minerals themselves also vary widely. Some gas is usually found present with oil, either as a "cap" or dissolved in the oil. In such cases, the pressurized gas is a valuable aid in forcing oil through the porous rock and into well bores. Gas also is often found alone or without significant association with oil. The degree and nature of the gas-oil association are not precisely predictable in advance of actual discovery in particular formations. Even nonassociated gas is most often found when the primary object of search is oil.

The exploration phase of the oil and gas production cycle begins with geological surveys to identify generally promising areas for more intensive investigation. These are followed by lease acquisitions, which are more or less expensive depending upon the supposed quality of the underlying prospects and the degree of competition among interested parties. The next step is geophysical testing,[4] such as by seismographic analysis, to locate beneath the surface specific geological formations capable of trapping oil and gas. If these tests yield poor results, leases may be abandoned without drilling; if they yield good results, exploration is completed with the drilling of one or more wells to the target formation. The uncertainty remaining after the typical amount of predrilling exploration is indicated by the fact that about nine out of ten exploratory wells are dry.

The development phase of the oil and gas production cycle begins with a discovery that is evaluated as worth the additional investment required to put it into production. Development consists of drilling appropriately spaced wells to the bearing formation and equipping these wells with flow regulators, pumps, storage tanks and gathering pipelines. The process incidentally involves discovery of the exact limitations of the producing formation and the operating characteristics--pressure, porosity, etc.--of the reservoir. When development is completed, dry holes mark the limits of the reservoir as well as anomalies within it. Some wells may be drilled for purposes of reinjecting gas or water and thereby maintaining reservoir pressure.

Outlays on exploration and development in the oil and gas industry are capital investments corresponding to plant and equipment expenditures in other industries. In recent years, domestic exploration and development outlays of the industry have exceeded $4 billion annually. Exploration accounts for about 40 percent of the total, development for the remaining 60 percent.[5]

The final phase of the production cycle is extraction. As a process, it is essentially continuous and largely automatic, the extractive force being pressure differential supplied either naturally or by means of pumps. Consequently, extraction costs typically are small in relation to exploration and development costs. Put another way, the great bulk of the charges to current income from extraction are indirect (and fixed) costs associated with exploratory and developmental capital outlays. Even the labor costs of operating a reservoir, chiefly for record-keeping and for general supervision and maintenance of the wells and their equipment, are in the main fixed over a wide range of output. Other than user costs, the principal variable costs are fuel costs and severance taxes.

III. Supply in various decision periods

We now consider the determinants of oil and gas supply in different decision periods. We begin with the shortest period, corresponding to the extraction phase, in which only a few costs are variable, and proceed in two steps to the longest period, corresponding to the exploration phase, in which all costs are variable. At each step in the analysis we shall attempt to indicate the supply characteristics that help explain the large extent of governmental interference with this industry.

A. Supply in the extraction decision period. Assume in operation a given number of oil and gas reservoirs of specified quality, these being the result of past exploratory and developmental effort. (The costs of such effort are sunk, of course.) At first, assume each reservoir to be operated by a number of competitive producers, without mutual agreement or public regulation. The decision before the several operators is the rate of extraction from each property at any point in time--and, by implication, the time-distribution of total recovery from each reservoir over its operating life.

In the interest of maximizing his income, each operator will at every point in time push the rate of extraction from his property to the point were marginal cost--the increment to total costs resulting from the last unit extracted--equals the going price. The relevant marginal cost is the sum of two components: marginal direct cost and marginal user cost. Marginal user cost for the individual competitive operator is, in turn, the sum of three components: marginal user cost of timing, marginal user cost of nonrecovery, and marginal user cost of competitive extraction.[6]

Marginal user cost of timing is the discounted present value of the net receipts (gross receipts less direct costs) sacrificed in future by extracting a unit now that might have been extracted at a later time. Given the total recoverable oil and gas in a reservoir, a unit produced now is a unit that cannot be produced later; a cost of producing a unit now therefore is the present value of the future income consequently sacrificed. Marginal user cost of nonrecovery stems from the fact that, at least beyond some critical point, ultimate recovery from an oil reservoir is inversely related to the rate of extraction per unit of time. (In general, this is not true of nonassociated gas reservoirs.) Thus marginal user cost of nonrecovery is the discounted present value of the net receipts sacrificed in future through additional nonrecovery resulting from a unit extracted now.

Marginal user cost of competitive extraction is of an entirely different nature. It stems from the "rule of capture," under which an operator is entitled to oil and gas produced through wells located entirely on his property, even though the minerals may have migrated underground from adjoining properties. Thus, marginal user cost of competitive extraction is the present value of the net receipts sacrificed to a neighbor as the result of extracting a unit now from one's own property. The cost is negative, of course. A unit extracted now is a unit that cannot be lost to a neighbor; a unit not extracted now is a unit potentially lost to a neighbor.

Marginal user costs obviously depend upon expected future prices and extraction costs. The higher are expected future prices and the lower are expected future costs of extraction, the larger is the present value of future net receipts sacrificed by extracting a unit now. Thus, for instance, the expectation of rising prices raises the marginal user costs of timing and of nonrecovery and reduces current supply, while the expectation of falling prices lowers the marginal user costs of timing and of nonrecovery and increases current supply.

To repeat, it maximizes the individual competitive operator's income if he pushes the rate of extraction from his property to the point where marginal cost equals price. But the negative component of marginal user cost--marginal user cost of competitive extraction--may entirely offset the positive components--marginal user costs of timing and of nonrecovery. If so, the rate of extraction is pushed to the point where only marginal direct cost equals price. There are two undesirable consequences of that. First, supply becomes quite inelastic, even at very low prices. Consequently, price is highly unstable in response to fluctuations in demand (as over the business cycle). Second, since the negative marginal user cost of competitive extraction is a purely artificial private cost, extraction is pushed to the point where the actual marginal cost of all operators exceeds the price. Thus, even if the market-clearing price yields a net income to operators collectively, that income is not maximized within the constraints of the opportunity. In effect, wastes are imposed upon the system of extraction, these taking the specific forms of improper distribution of extraction in time and loss of ultimate recovery. These imposed wastes reduce supply from each reservoir over its life as a whole.

There are two general approaches to removing or limiting the wastes caused by competitive extraction from common reservoirs. The first, and in principle most satisfactory of these, is to operate each reservoir as a unit, dividing the proceeds from extraction among the various leaseholders on the basis of some equitable formula. This approach simply removes the source of negative marginal user costs of competitive extraction and allows unit managers, on behalf of all leaseholders, to make extraction decisions on the basis of actual marginal costs. Marginal user costs of timing and of nonrecovery are in effect freed to perform their extraction-limiting function at any point in time, particularly when current prices tend to fall relative to expected future prices. Supply consequently is more elastic than under free competitive extraction. All producing states permit and even encourage voluntary unitization agreements, but only a few--and those not the principal producing states--provide any compulsion in unitizing oil and gas reservoirs.

The other approach--the one almost universally used in the United States--is to regulate production directly, assigning production quotas by wells to leaseholders. The total allowable production typically is limited by the smaller of (a) the sum of the reservoir extraction rates consistent with near-maximum ultimate recovery or (b) the total quantity demanded at the going price, whatever that may be.[7] Well quotas are based on relatively inflexible formulas in which well density and depth are the usual arguments. The quota formulas usually encourage dense well drilling to maximize leasehold allowables, so it is necessary to regulate well-spacing also. This approach looks not to removing the source of negative marginal user costs of competitive extraction, but rather to controlling operators' responses to such costs by means of detailed regulation. The administrative necessity of relying upon formulas prevents the flexible adjustment of marginal cost to price required for continuous income maximization. The system generally eliminates wastes of nonrecovery, but students of the industry are agreed that it stimulates excessive drilling and overcapacity.[8] The wastes it permits, while far less than those of free competitive extraction, significantly reduce supply from each reservoir over its life as a whole.

In the extraction decision period, the special income tax allowances for oil and gas have little or no effect on supply under either unitization or regulation approaching the conditions of unitization. The reason is that the allowances have roughly offsetting effects on current net receipts and marginal user costs. Under free competitive extraction, with marginal user costs depressed perhaps to zero because of the negative component in them, the special allowances encourage excessively rapid exploitation and reduce supply from each reservoir over its life as a whole.

B. Supply in the development decision period. Assume now a given number of undeveloped oil and gas discoveries of specified quality, these being the result of past exploratory effort. (The costs of the exploratory effort are sunk, of course.) The decision before the several operators is the rate of investment in development wells and equipment with a view to making new extractive capacity available. In effect, the decision determines the supply of developed reservoirs, which supply becomes the principal basis of oil and gas supply in the extraction decision period.

Again with a view to maximizing his income (or rather the present worth of it), each operator will push development investment to the point where the present value of the expected increment to net receipts from the last investment is just equal to the associated increment to total investment outlays. In forming estimates of incremental net receipts, the operator must consider total recoverable oil and gas in each reservoir, the nature of the gas-oil combination, the probable time-distribution of recovery, the associated degree of avoidable nonrecovery, and the probable time-path of prices and extraction costs over the operating life of the reservoir. The necessary increment to total investment outlays is affected by depth and similar influences on drilling costs, accessibility of drilling sites, and the number of wells consistent with the probable time-distribution of recovery.

Other factors being the same, the higher the expected level of oil and gas prices, the lower the quality of discovery it is economical to develop. Thus, the elasticity of supply in the development decision period reflects the qualitative distribution of discoveries made through exploration. No discovery will be developed unless the expected price will cover expected extraction costs plus development costs, while an already developed reservoir will be operated if the price covers no more than extraction costs. Consequently, the elasticity of supply in the development decision period is greater than that in the extraction decision period.

The general level of supply--the size of the quantities made available at different prices--in the development decision period varies directly with the efficiency of extraction expected. Under free competitive extraction, avoidable nonrecovery of oil and gas and the number of wells each operator must drill both are large relative to the situation under unitized operation of reservoirs. Consequently, given the quality of discoveries available for development, the number it is economical to develop at each expected price level is smaller under free competitive extraction than under unitization; which is to say, supply is smaller under free competitive extraction than under unitization. For similar reasons, but to a lesser degree, supply is smaller under the prevailing system of detailed production regulation than under unitization.

The special income tax allowances for oil and gas have a significant effect on supply in the development decision period. Relative to a situation of equal taxation of income from all sources, they increase the net receipts from extraction at any given price level and thus increase the number of discoveries it is economical to develop at each expected price level.[9] In short, they increase supply in this period.

C. <u>Supply in the exploration decision period</u>. At the outset of the exploration decision period, operators are confronted with an array of general prospects of various supposed qualities. Knowledge of these prospects is generally available; no significant costs are sunk at the beginning of the decision period. The decision before operators is the rate of investment in exploration with a view to making new discoveries available for development.

As with development, each operator will push exploratory investment to the point where the present value of the expected increment to net receipts from the last investment is just equal to the associated increment to total investment outlays. The factors relevant to expected net receipts from exploration are the same as those in the development decision, except that expected development outlays enter as additional negative arguments. The necessary increment to investment outlays reflects accessibility of prospects, depth of promising formations and the difficulty of drilling through intervening formations.

The elasticity of supply in the exploration decision period reflects the qualitative distribution of available prospects. Since no prospect will be fully explored unless the expected price of oil and gas will cover expected exploration plus development plus extraction costs, while an already discovered deposit will be developed if the expected price will cover only expected development plus extraction costs, the elasticity of supply in the exploration decision period is greater than that in the development decision period. Whatever the level of demand in this longest of decision periods, the market-clearing price covers full costs of the complete production cycle.

For reasons identical with those given in the discussion of the development decision period, supply in the exploration decision period is reduced by the wastes of free competitive extraction and detailed production regulation relative to unitized operation of reservoirs; and is increased by the special income tax allowances relative to a situation of equal taxation of income from all sources.

IV. <u>The price of oil and gas in the very long run</u>

As a country such as the United States continues to use domestically produced oil and gas in large--even increasing--amounts, at some point the quality of remaining exploratory prospects inevitably begins to decline. Oil and gas must be searched for in less accessible places, at greater depths, in leaner deposits. The long-run supply thus tends to decline, and the market-clearing price tends to rise.

We have long since passed the point of declining quality of prospects and have thus far averted rising relative prices only through continued progress in the technology of finding and extracting oil and gas and gradual reduction of the wastes of competitive extraction.

Today, the price of crude oil in the United States would not be nearly as high as it is were it not insulated from foreign competition; and the volume of production would not be as great as it is at that price were it not for the special income tax allowances. The price is no higher than it is at least partly because at slightly higher prices shale oil would make significant competitive inroads into crude oil markets. The price of domestically produced gas is freer of threats from foreign sources and substitutes but, assuming the regulatory authorities will continue to permit increases over time, it will not always be. Under these circumstances, the primary issue raised by the long-run supply of oil and gas is not the course of prices and the availability of fuels, but rather the survival of the oil and gas industry as we know it. If supply decreases with deteriorating exploratory prospects, the industry must shrink accordingly.

There are two lines of escape. First, the industry and its legislative friends can accelerate improvements in the regulatory system, moving ideally toward universal unitization of reservoirs and relaxation of detailed formula regulations. The potential cost reductions in this area may be as much as one-third the going price. Second, the industry can devote still more effort to technological improvements. The areas offering the greatest scope for improvement are predrilling exploration technique, drilling technique and recovery of oil in place. The progress already made in these areas gives reason for hope that the price of oil and gas may actually decline, and the industry may renew its growth, in the decades immediately ahead.

FOOTNOTES

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1. Under the "rule of capture," an operator is entitled to oil or gas produced through wells located entirely on his property, even though the minerals may have migrated in response to gravity or pressure differential in the natural reservoir from the property of others. The rule, if unmodified by mutual agreement or regulation, obviously provides incentive for rapid, competitive exploitation of a common reservoir by multiple leaseholders.

2. The condition of many actual and potential sellers prevails in the oil and gas industry. Accordingly, for purposes of this paper we ignore the characteristics of supply in industries where this condition is absent.

3. User costs reflect consumption of capital resulting from use, as distinguished from mere passage of time.

4. Depending upon the exact situation, some geophysical testing may occur in advance of leasing.

5. American Petroleum Institute, Independent Petroleum Assn. of America, Mid-Continent Oil and Gas Assn., Joint Association Survey, 1960 (Dec. 1962). The Survey indicates that exploration costs are close to one-half of total exploration and development outlays. However, the Survey's cost classification scheme assigns all dry hole costs to exploration, even though about one-half of all dry holes are drilled in developing proven discoveries.

6. The user cost terminology is based on Paul Davidson, "Public Policy Problems of the Domestic Crude Oil Industry," American Economic Review, March 1963, pp. 91-96.

7. This obviously leaves the market-clearing price indeterminate. Presumably it is set by some price leader on the basis of average cost plus target profit. Ironically, average cost varies inversely with the volume of output permitted.

8. For a more detailed discussion of these wastes, see James W. McKie and Stephen L. McDonald, "Petroleum Conservation in Theory and Practice," Quarterly Journal of Economics, February 1962, pp. 98-121.

9. This is not to say that the allowances increase the number of discoveries it is economical to develop relative to a situation of no income taxes at all. For detailed discussion of the effects of the allowances, see Stephen L. McDonald, Federal Tax Treatment of Income from Oil and Gas (Washington: The Brookings Institution, 1963).